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Does the different sectoral coverage matter? An analysis of China's carbon trading market

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ABSTRACT

By the end of 2017, China formally established the national carbon trading market, however, only electricity industry was eligible to participate in the emission trading scheme (ETS). This paper aims to answer the question as to what should China do after the first step of establishing China's national ETS market using a dynamic recursive CGE model with six scenarios from different coverage according to relevant documents. The results show that when more industries are covered in ETS market it will lead to a higher GDP performance and less ETS price in general. Since the trading price is related to the marginal emission reduction cost of enterprises, the coverage of enterprises with low emission reduction cost can bring lower prices. However, there is no direct relationship between carbon price and emission reduction, as the coverage is different in different. There is no obvious relationship between the additional burden of enterprises and emission reduction, it is only related to carbon price and the coverage. Finally, we find that after covering the power generation industry, the carbon market should cover other primary energy production enterprises, which will bring much better emission reduction benefits than the original plan of the National Development and Reform Commission in China.

1. Introduction

The climate change caused by Greenhouse gases has become a major issue that the world needs to solve (Zhang et al., 2019). As the largest emitter country, China participates in global efforts actively to curb global warming. After the *11*th *Five-Year Plan*, China has introduced a number of policy plans intensively to form a policy system for low-carbon and green development. In the *12*th *Five-Year Plan*, China proposed that the nation's Emission Trading Scheme (ETS) market should be established gradually, as its ability to cope with climate change only relies on market forces rather than administrative measures.

Many experts have been contributing a lot to cope with the problems of CO_2 reduction or energy saving (Lin and Jia, 2019a). Sustainable development and ECO development have become hot topics nowadays (Moran et al., 2008; van Weenen, 1995). Low-carbon economy and low carbon policy are currently the mainstream of coupling with environmental change and many mitigation tools have been studied or implemented such as carbon tax (Caron et al., 2018; Macaluso et al., 2018), carbon sinks (Bastviken et al., 2011; Ritter et al., 2017) and ETS (Babatunde et al., 2017; Li and Jia, 2016; Liu et al., 2015; Tol, 2018). Today, there are many emission trading markets in the world, such as EU-ETS (Verde et al., 2019), RGGI (Fell and Maniloff, 2018), CCX (Gans and Hintermann, 2013), NSW-GAAS (Passey et al., 2008) and China's pilot and national ETS (Lin and Jia, 2019b; Liu and Fan, 2018; Tan and Wang, 2017). Studies that focused on ETS can be classified into three aspects: 1) the introduction and prediction of ETS, 2) the impact or evaluation of ETS and 3) design or construction of ETS, or behaviors under ETS.

For the first aspect, Oh et al. (2017) depicted different design backgrounds of ETS characteristics in developing and emerging countries, as well as a case study in Korea. Zhu et al. (2017a) used two methods to predict carbon prices: decomposition of empirical mode and vector regression of evolutionary least-squares support. Khaqqi et al. (2018) proposed a novel ETS mechanism integrating the consideration for Industry 4.0, and depicted that the mechanism of ETS may be a better scheme and that the value of benefits is greater than the value of its drawback as its implementation. Zhu et al. (2017b) studied on China's abatement potential of the iron industry and steel industry by using quantitative assessment in the ETS market and they argued that the CO_2 reduction potential might be underestimated. Xia and Tang (2017) estimated interregional embodied emissions and derived cost curves for

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regional marginal abatement by proposing a multi-region input-output model. Chang et al. (2018) analyzed dynamic relationship between energy prices and ETS prices and found that the obstacles between them are controlled energy pricing and overreaction of ETS market. Rose et al. (2018) predicted that additional 0.2–0.4% cost of GDP will be burdened as UK is leaving EU-ETS if they want to achieve the reduction target.

For the second aspect, Wu et al. (2017) evaluated the economic effects of policies of ETS and renewable energy generation. Dai et al. (2018) conducted a similar study on the same topic but considered China's reduction target. Cao et al. (2018) investigated the influences of ETS and several subsidy policy on production industries as well as CO_2 reduction level of a manufacturer, they explored which option of these policies is better for society, and found that carbon emission reduction level will increase with the ETS price increase, whereas it will be hardly changed with the variations of low-carbon subsidies. Ju and Fujikawa (2019) analyzed the cost transmission mechanism in China's ETS market and found most sectors would not suffer a great increase, which results are similar to some of relevant literatures Lin and Jia, 2018.

For the third aspect, Lin et al. (2016) showed that adjustable feed-in-tariffs are based on the evolution of emission trading prices in order to propose China's climate policy package with the consideration of cost-effectiveness by presenting a simple method. Mehling and Haites (2009) analyzed the possibility of linking the ETS markets, and proposed that most obstacles are recognition of allocating emission allowance and certified emission reductions. Liu et al. (2017) studied the efforts of enterprises in EU-ETS to maximize profit and minimize cost during the allowances trading in Phrase II. Wadud and Chintakayala (2019) brought some thoughts to us about the trade-off between in-home and transport in personal carbon trading and indicated it is difficult to reduce emissions at personal level. Eikeland and Skjærseth (2019) analyzed the reaction of oil and electricity industries and found that responses of the electricity industry are more positive than that of the petroleum industry. Cludius et al. (2019) evaluated cost-efficiency of EU-ETS in period II and uniformly supported the theoretical cost-efficiency of EU-ETS.

The National carbon trading market in China officially started on December 19, 2017 and China's government proposed *National carbon emission trading market construction plan (power generation industry)*, which is the first official document of China's national ETS (National Development and Reform Commission, 2017). It can be confirmed that China's carbon trading system has officially started although only the power industry is involved. Therefore, studies about which industries are suitable aside the electricity sectors to participate in the carbon trading system becomes very meaningful.

The research on sectoral coverage has been studied by many scholars (Pang et al., 2018; Qi and Cheng, 2018). Dijkstra et al. (2011) found the positive impact of extending the sectoral coverage of an international ETS. Lin and Jia (2017) suggested the patterns of phase I and II of EU-ETS. Qian et al. (2018) believed that covering industries with high emissions and high energy intensity can lead to the highest emission reduction effects and will also moderate economic and welfare losses. Most literature argues that more coverage will result in greater reduction and lower reduction cost (Mu et al., 2018). Other literature holds different opinions, such as Wang et al. (2018) found no inherent relationship between the market structure and the efficient coverage of the allowance market. However, based on the study, we believe that the coverage with only energy production enterprises may be better than those with energy intensity, providing new ideas for ETs policies. Little research have focused on the real event of China's ETS market. The research on this topic is almost blank. Therefore, this paper aims to answer the question as to which industries are suitable to follow electricity sectors into the carbon trading system. We hope this paper can play a certain reference role for China's policy makers, as well as policy makers in other ETS market, in selection of better industries to participate in future ETS markets. The innovations and contributions of this paper are as follows:

1) Based on the current policy of China's pilot ETS market, this paper discusses the potential options of sectoral coverage in China's national ETS market in the future. The conclusions of this paper will serve as a reference for policy makers. As almost no paper considers the construction of the carbon market from this perspective, thus this paper will fill the knowledge gap.
2) This paper constructs a dynamic recursive CGE model to study the effect of ETS coverage options and it also explains how to convert CGE model from static to dynamic, which will serve as a reference for CGE modelers on how to set up a CGE model with carbon emission trading block.
3) This paper draws relatively new conclusions: we found it is better to cover energy production industries into ETS market rather than energy intensive industries. The corresponding analyses and explanations are given in section 5 and section 6.

This paper is organized as follows: section 1 introduces the background and literature review of ETS. In section 2, status of China's carbon market is presented. The methodology is provided in section 3. Section 4 shows the data source and describes scenario design. The research results and discussions are provided in section 5. The conclusions, policy implications and limitations are proposed in section 6.

2. China's carbon market

At the end of October 2011, the National Development and Reform Commission in China approved five pilot cities and two provinces (Beijing, Tianjin, Shanghai, Chongqing, Hubei, Guangdong, and Shenzhen) to conduct carbon emissions trading pilot, and later in 2017, Fujian became the 8th pilot area. Since 2011, the pilot areas have carried out various basic tasks, including the formulation of local laws and regulations, the determination of total control objectives and coverage, the establishment of greenhouse gases measurement, reporting, and verification systems, the allocation of emission allowances, the establishment of trading systems, development of registration systems, establishment of special management agencies, establishing market supervision systems, etc., and finally formed a comprehensive and complete carbon trading system.

The *China-U.S. Joint Presidential Statement on Climate Change* issued on September 25th, 2015, indicated China's plans to launch a nationwide carbon emission trading system in 2017 and coverage of key industries such as: electricity, chemicals, building materials, paper, nonferrous metals, iron and steel (The Central People's Government of the People's Republic of China, 2015).

National carbon emission trading market construction plan (power generation industry) was proposed on December 19, 2017 (National Development and Reform Commission, 2017). The document revealed that only the power generation industry will participate in ETS market in the first step of ETS construction. However, more industries will be covered and according to the plan, the national ETS market will cover 340–400 million tons of carbon dioxide emissions, which will make China's carbon market the world's largest carbon market, it may be twice as EU-ETS. Because of the huge reduction potential, the carbon market in China has a profound impact on the world's road to emission reduction. Therefore, it is very meaningful to study the future trend of China's carbon market.

3. Methodology

3.1. CGE model

Computable General Equilibrium (CGE) model is a model widely utilized for analyzing policies of energy and environment (Borgomeo et al., 2018; Dovì and Battaglini, 2015; Siagian et al., 2017). Different from input-output model (Chen et al., 2018; Cui et al., 2015) and econometric analysis (Tan et al., 2018b, Tan et al., 2018), CGE model can analyze the impact of a target issue on the whole society better. Three characteristics of CGE model (He and Lin, 2017; Hosoe, 2018; Wu et al., 2014) are summarized below.

1) The supply and demand function clearly reflect the behavior of producers pursuing profit maximization and consumers pursuing maximization of utility.
2) The quantity and relative price are both endogenous in the model, and the resource allocation method is determined by the general equilibrium model structure with Walras's law.
3) The focus of this model is on simulating the physical aspect of the economic entity. The resources of the economy in the model have been fully utilized.

The basic modelling structure is according to Lin and Jia (2019b), which consists of five blocks: production block, income-expenditure block, trade block, energy-policy block, and macroscopic-closure & market-clearing block. The CGE model will be introduce briefly.

3.1.1. Production block

The framework of the production block in the CGE model is depicted in Fig. 1. This block has four levels of nesting. Except for the output bundle in the top, most follow Constant Elasticity of Substitution (CES) production function. While output bundle consists of factor input and intermediate input following Leontief production function, like many other studies (Breisinger et al., 2019), as there are tremendous of intermediate inputs being considered in this bundle. The elasticity of production block is set in accordance with AIM/CGE2.0 (Fujimori et al., 2012).

Although most studies on CGE models separates oil and gas industries, the split method is quite crude: the difference of intermediate input is not considered and the dominated fossil energy is coal, this paper does not separate the two industries.

3.1.2. Income-expenditure block

The block expresses the behavior of the four factors: households, government, enterprises and the rest of the world. The trade deficit is given by exogenous, which is according to several relative guidebooks and literature (Hosoe, 2004; Hosoe et al., 2010).

3.1.3. Trade block

Armington commodities are introduced into this CGE model to simulate the integrated consumption of household, government and domestic enterprises (He et al., 2014; Lin and Li, 2012). By using CES function, we can differ domestic production-domestic consumption goods and import goods from domestic consumption (Armington consumption). Using CET (Constant Elasticity of Transformation) functions,

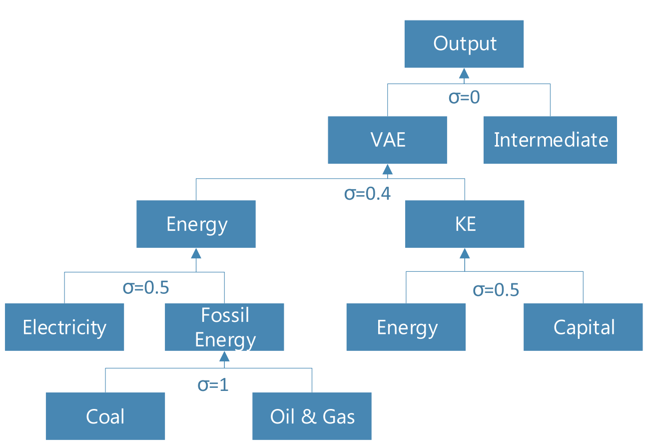

Fig. 1. The framework of production block in CGE model.

Table 1
Capital depreciation rate of each sector.[a]

Sectors	AGR	COL	O_G	PAP	CMT	FER	CMC
the rate of depreciation	0.05	0.062	0.065	0.055	0.055	0.056	0.055
Sectors	**STL**	**EQU**	**ELC**	**CST**	**TRA**	**OTH**	**SER**
the rate of depreciation	0.055	0.062	0.048	0.055	0.052	0.055	0.045

[a] The abbreviation is explained in Table 2.

we can simulate enterprises' distributions of production in domestic market and international market.

3.1.4. Energy-policy block

This block is the simulation of ETS market. The rate of free allowance (free distribution part of carbon allowance) will be 0.9 in the period 2017–2030, which setting follows the patterns in Guangdong pilot[1] in China as well as the period I in EU-ETS, as there is no relative detail description in *National carbon emission trading market construction plan (power generation industry)* (National Development and Reform Commission, 2017), which is the first official document of China's national ETS market. This paper assumes that carbon emission allowance is calculated by grand fathering methods. This block can be explained by the following three equations.

$$EM_i = EM\_COAL_i + EM\_O\_G_i \tag{1}$$

$$\begin{aligned} PLC_{ei} &= p^t(CA_{ei} - FA_{ei}) + p^f(EM_{ei} - CA_{ei}), EM_{ei} \geq CA_{ei} \\ PLC_{ei} &= p^t(CR_{ei} - FA_{ei}), EM_{ei} < CA_{ei} \end{aligned} \tag{2}$$

$$fpr = \sum_{ei} FA_{ei} \Big/ \sum_{ei} CA_{ei} \tag{3}$$

Where EM_i represents the total emission of a sector. EM_COAL_i and $EM\_O\_G_i$ represents CO_2 emissions by different fossil fuels in the sector *i*. PLC_{ei} depicts the policy cost (enterprise burden) in the sector *ei*. The subscript of *ei* represents the coverage industries under the ETS. p^t is carbon price while the p^f represents the fine for over-emission. CA_{ei} denotes carbon allowances of the sector ei. FA_{ei} represents the free part of the carbon allowance, while *fpr* shows the rate of free payment.

3.2. Model dynamics

This paper uses a recursive method to construct a dynamic CGE model that is static. Some key exogenous parameters are changed by the period of the year, such as factor endowment (labor and capital), and technical progress. Capital depreciation is determined by the capital stock of the current period and investment. The capital stock is endogenous except for the first period, while investment is endogenous. The capital depreciation rate is illustrated in Table 1 which is set according to Lou (2015).

Labor endowment is exogenous and determined by *National Population Development Plan (2016–2030)* (The Central People's Government of the People's Republic of China, 2017). Autonomous Energy Efficiency Improvement (AEEI) in the CGE model is considered in this study according to the relevant literature (Lin and Jia, 2019) and *Medium and Long-term Energy Saving Special Planning* (National Development and Reform Commission, 2005).

[1] Implementation Plan of Carbon Emission Allowance Allocation in Guangdong Province in 2018 http://zwgk.gd.gov.cn/006939756/201807/t20180725_774704.html.

4. Data source and scenario design

4.1. Data source and social accounting matrix

China's input-output table is used to construct social accounting matrix which is a basic data of CGE model (China Input-Output Association, 2015). For analyzing energy issues, an energy balanced table is constructed and the data of this table is obtained from China Statistical Yearbook (National Bureau of Statistics, 2015). Compared with *Global Carbon Budget 2017* (Le Quéré et al., 2017), we declare that the CO_2 emissions discussed is only from energy consumption, without Biological breath, microbial decomposition, and carbon sinks and carbon emissions from land and sea. Sector classification is depicted in Table 2.

4.2. Scenario design

According to different documents in different periods, we propose five scenarios with different coverage industries. A BaU (Business as Usual) scenario and five countermeasure scenarios are constructed as shown in Table 3. The model is dynamic model over 2012–2030 year period. In addition, it is simulated that China started a nationwide carbon trading market since 2017.

Following are the descriptions of scenario settings:

1) BaU scenario. BaU scenario assumes that there is no ETS market in 2017–2030.
2) ELC scenario. ELC scenario assumes that only electricity industry is covered in ETS market in 2017–2030.
3) ECC (electricity, chemical, and cement) scenario. In July 2017, the progress of measurement, reporting, and verification of CO_2 emissions in some provinces was severely delayed, and the quality of data was low. National Development and Reform Commission in China decided that the first batch of coverage industries should only be electricity, chemical, and cement, which have better databases.
4) ENINT (energy-intensive) scenario. According to the plan proposed by China's development and reform commission on January 2016, the first phase will cover key emission companies in the eight industries of petrochemicals, chemicals, building materials, steel, non-ferrous metals, paper, electricity, and transportation. This situation is simulated by the ENINT scenario that all of energy intensive industries are covered.
5) ENPRO (energy production) scenario. In phase I of EU-ETS, energy production industries are covered in the market. We, therefore, simulate a condition that ETS only covers energy production industries in 2020–2030.
6) EUETS-III scenario. In EUETS-III scenario, almost all of the energy and energy-intensive industries. It is set according to phase III of the EU-ETS, and the coverage is the same as coverage industries in ENINT scenario added the coverage in ENPRO scenario.

Table 2
Description and coverage of sector classification and population classification.

Sectors	Description
AGR	Agriculture, forestry, animal husbandry and fishery
COL	Coal mining and washing industry
O_G	Petroleum and natural gas exploitation
PAP	Paper industry
CMT	Cement
FER	Chemical fertilizer
CMC	Chemicals
STL	Steel smelting and rolling processing industry
EQU	Equipment manufacturing industry
ELC	Electricity
CST	Construction industry
TRA	Transportation
OTH	Other industry
SER	Service
RUR	Rural population
CTZ	Urban population

5. Results and discussion

5.1. The impact on economy

5.1.1. GDP

Fig. 2 illustrates GDP in all countermeasure scenarios compared with BaU scenario in 2030. The bars express the amount of GDP (left ordinates) and the line expresses GDP loss rate compared with BaU scenario (right ordinates). If China does not establish ETS market, 2030 GDP will be 86.86 billion (price at 2012 level). However, the establishment will reduce China's GDP directly to some extent. As Fig. 2 shows, GDP will be 85.63, 85.65, 85.69, 85.54 and 85.71 trillion yuan, or suffer 1.44%, 1.41% 1.36% 1.54% and 1.34% reduction in ELC, ECC, ENINT, ENPRO, and EUETS-III scenarios respectively. Moreover, GDP loss is somehow sensitive to the choice of coverage industries. The GDP loss will be 1.23, 1.20, 1.17, 1.32 and 1.14 trillion yuan in ELC, ECC, ENINT, ENPRO, and EUETS-III scenarios, respectively. The largest decline in GDP will occur in ENPRO scenario. The next will be ELC and ECC scenarios. The results indicate that more coverage will lead to a higher GDP performance (however, the CO_2 reduction capacity all also be different, which can be seen in section 5.3), moreover, it seems like that only covering energy production industries into ETS market will result in more GDP loss. The reason why different scenarios have different GDP performances could refer to the discussion in section 5.1.3 (commodity prices and domestic output).

5.1.2. International trade

The changes in exports in countermeasure scenarios compared with BaU scenario in 2030 are illustrated in Fig. 3. Exports in energy production industries will decrease sharply: the export of coal, oil and gas, and electricity will reduce 30.63–43.90%, 18.21–27.85% and 43.19–52.44% respectively. The industry that is not covered is less affected, by 0.47–7.24% reduction. Commodity exports are very sensitive to the coverage of the industries. For instance, cement is covered in ECC, ENINT and EUETS-III scenarios and the reduction will be 22.27–30.16%, while it will be 6.21–6.28% in ELC and ENPRO scenarios. Exports in all industries will decrease with a different range, which reason is simple: ETS makes the cost of coverage industries increasing, which will lead to the increase in the prices of commodities up as well as the output decrease so that the ability to export to the rest of world will decline, especially in energy production sectors.

The changes in imports in countermeasure scenarios compared with BaU scenario in 2030 are depicted in Fig. 4. ETS impact on imports will not be obvious as that on export. Most of the commodity import changes are not more than positive and negative 8%, except for fossil energy production sectors, such as coal, oil and gas industries. The reason why ETS impact on import is not significant compared with that on export is that exports are mainly determined by domestic output, and imports are mainly determined by domestic consumption. Moreover, ETS will directly affect domestic output, rather than domestic consumption.

5.1.3. Prices of goods and the domestic output

Fig. 5 shows that the prices of goods in all industries compared with BaU scenario in 2030. The industrial coverage will significantly influence goods prices in these covered industries based on the findings. For instance, coal price will increase by 4.39–4.99% in scenarios in the ELC, ECC and ENINT scenarios. However, it will be 9.97–11.13% in ENPRO and EUETS-III scenarios, in which coal industry participates ETS market. The rule also applies to industries of cement, fertilizer, chemicals, steel etc. Also, the increase in electricity prices will reduce when more industries are covered by ETS markets. Its leading cause maybe that energy-intensive enterprises are under greater pressure to reduce CO_2 emissions than other enterprises, so the coverage of ETS will

Table 3
Scenario design of coverage industries.

Scenario	BaU		ELC		ECC		ENINT		ENPRO		EUETS-III	
Period	I[a]	II[b]	I	II	I	II	I	II	I	II	I	II
AGR	–	–	–	–	–	–	–	–	–	–	–	–
COL	–	–	–	–	–	–	–	–	–	C[c]	–	C
O_G	–	–	–	–	–	–	–	–	–	C	–	C
PAP	–	–	–	–	–	–	–	C	–	–	–	C
CMT	–	–	–	–	–	C	–	C	–	–	–	C
FER	–	–	–	–	–	–	–	–	–	–	–	–
CMC	–	–	–	–	–	C	–	C	–	–	–	C
STL	–	–	–	–	–	–	–	C	–	–	–	C
EQU	–	–	–	–	–	–	–	–	–	–	–	–
ELC	–	–	C	C	C	C	C	C	C	C	C	C
CST	–	–	–	–	–	–	–	C	–	–	–	C
TRA	–	–	–	–	–	–	–	C	–	–	–	C
OTH	–	–	–	–	–	–	–	–	–	–	–	–
SER	–	–	–	–	–	–	–	–	–	–	–	–

[a] Period I refers to the initial period of carbon trading market. This paper sets the preriod as 2017–2020.
[b] Period I refers to the developing period of carbon trading market. This paper sets the preriod as 2020–2030.
[c] C indicates that the industries is covered in ETS market in special period.

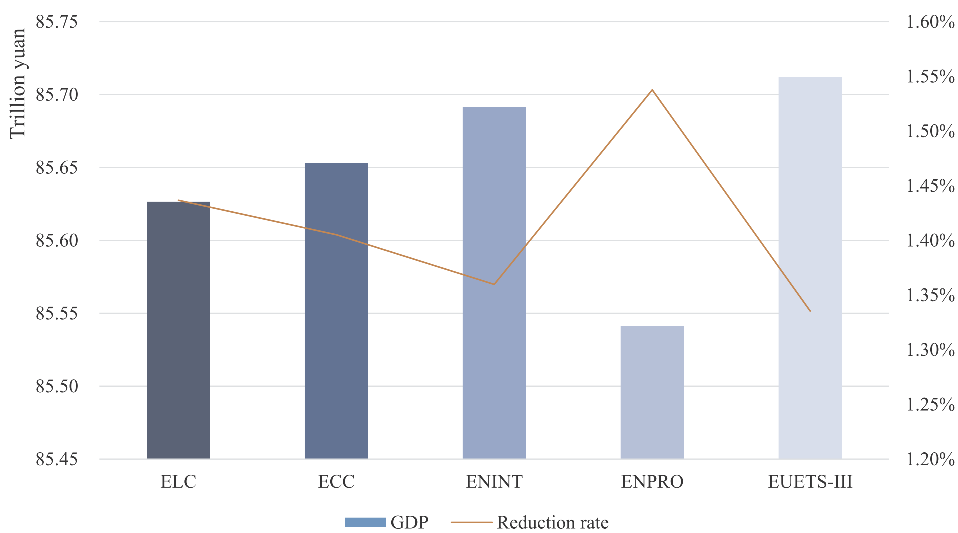

Fig. 2. GDP in all countermeasure scenarios compared with BaU scenario in 2030.

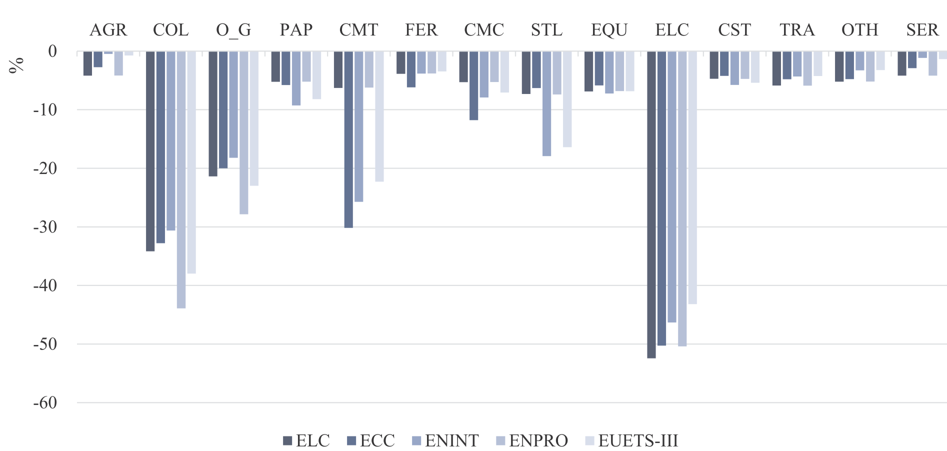

Fig. 3. The changes of export in countermeasure scenarios compared with BaU scenario in 2030.

significantly increase ETS price (shown in section 5.2.1). Additionally, as more enterprises participate, the lower the carbon trading price, the lower the burden on electricity industry. Moreover, we find that only coal and electricity prices will increase more than 10% in ENPRO scenario, indicating that the coverage of energy production sectors will directly affect the price increase in the energy production industry, and will indirectly drive CO_2 reduction of other companies through price factors.

Fig. 6 illustrates domestic output in all industries compared with BaU scenario in 2030. The changes in domestic output directly reflect the

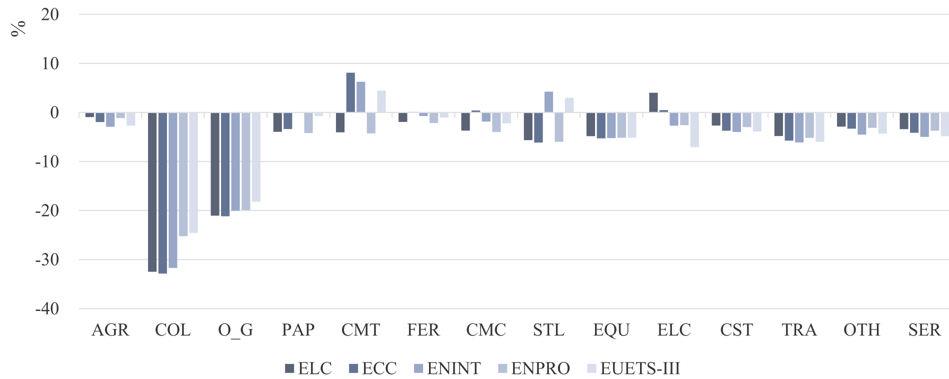

Fig. 4. The changes of import in countermeasure scenarios compared with BaU scenario in 2030.

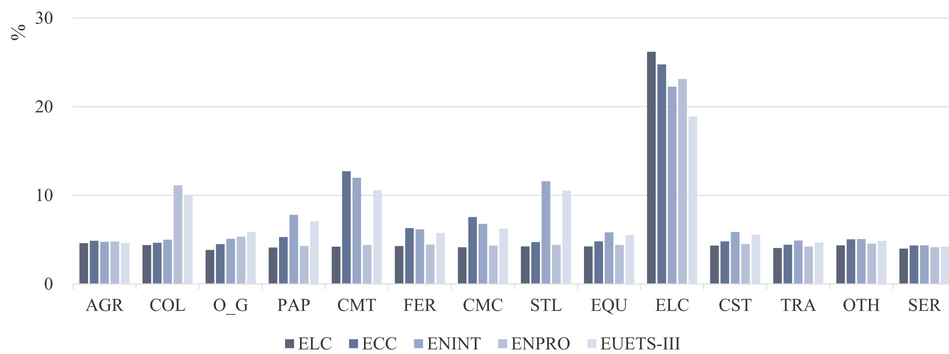

Fig. 5. Prices of goods in all industries compared with BaU scenario in 2030.

changes in GDP in section 5.1.1. Similar to the effect on ETS price, the coverage will significantly influence domestic output. The enterprises will reduce their output when they participate in the ETS market, especially in energy production sectors and some of energy intensive sectors like cement. The reason is simple: the coverage will directly affect commodity prices. Different coverage industries will bring different relative prices, and different relative prices will lead to different consumption choices of commodity market, ultimately bringing different output value of enterprises. The reduction of domestic output is similar to GDP loss, especially the reduction of other secondary industries and services (the two industries account for nearly half of the economic output).

5.2. The impact on ETS market

5.2.1. ETS price

Fig. 7 shows the ETS price in all countermeasure scenarios in 2030. In 2030, ETS price will be 562.78, 516.90, 448.17, 483.93, and 365.28 yuan/t-CO_2 in ELC, ECC, ENINT, ENPRO, and EUETS-III scenarios, respectively. The highest ETS price is the price in ELC scenario. We also find that the more industries are covered, the less ETS price will be. For example, the coverage industries in ELC, ENINT, and ENPRO scenario are the electricity sector, energy intensive sectors, and energy production sectors respectively, and the price in which will be 483.93–562.78 yuan/t-CO_2 while the price in EUETS-III which covered energy production sectors and energy intensive sectors will be 365.28 yuan/t-CO_2.

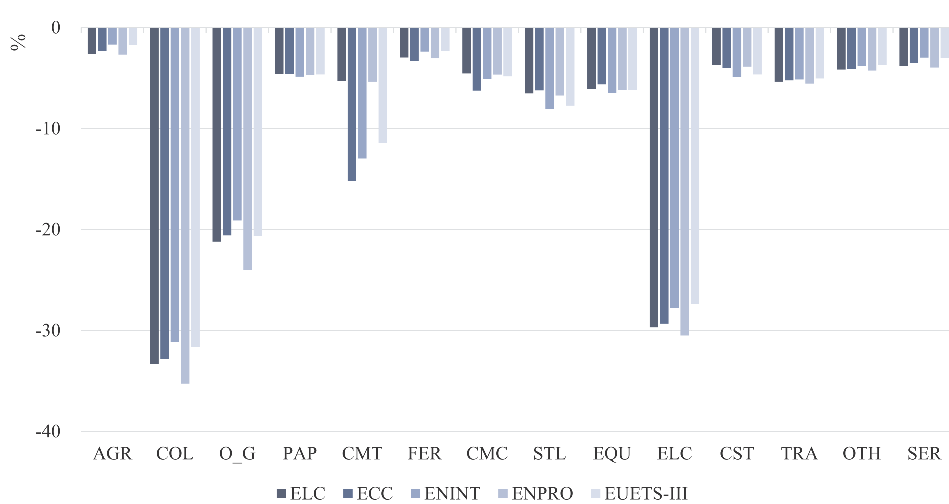

Fig. 6. Domestic output in all industries compared with BaU scenario in 2030.

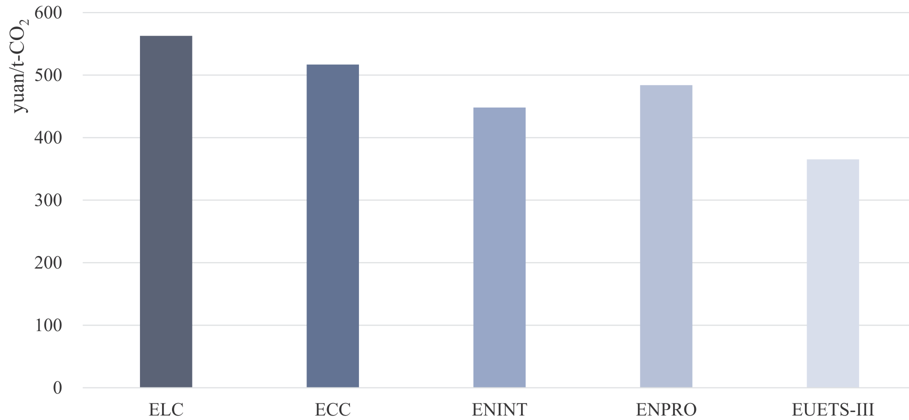

Fig. 7. Carbon price in all countermeasure scenarios in 2030.

We found that 1) as more industries are covered by the ETS market, the less ETS price; 2) ETS price will increase when energy intensity industries are covered. The reasons may be that energy-intensive companies are under greater pressure to reduce their emissions so that the inclusion of carbon trading will significantly increase the marginal abatement costs of ETS market (ETS price). However, when other companies participate in the market, they will become suppliers of carbon emission allowances for high-carbon ETS prices, which will reduce the abatement costs of the entire trading market to some extent.

5.2.2. Total enterprises burden

Total enterprise burden in ETS market in all countermeasure scenarios is depicted in Fig. 8. Enterprises' burdens are additional costs of enterprises caused by establishing ETS market, which is an indicator to measure the pressure on enterprises due to the existence of ETS. The highest enterprise burden scenario is ENINT scenario, where enterprises burden will be 1.20 trillion yuan. The next is EUETS-III and ECC scenarios by 1.13 and 1.04 trillion yuan. The burden of the enterprises is relatively lower in ELC and ENPRO scenarios than other scenarios by 0.92 and 0.94 trillion yuan. Although ETS price in ELC scenario is highest, the coverage industries are much less than others, so total enterprise burden is not as large as others, as well as that in ENPRO scenario. We found that if ETS only covers energy-intensive industries, the total enterprise burden will be higher than that in scenarios with other coverage choice.

The percentage of the enterprise burdens in different industries accounts for total enterprise burden in 2030 countermeasure scenarios as shown in Table 4. The enterprises' burden in electricity industries will be 915.17, 856.44, 769.59, 770.94, and 632.17 billion yuan in ELC, ECC, ENINT, ENPRO and EUETS-III scenarios respectively. We find that with the increase in the coverage industry, the pressure on the electricity industry will gradually decrease. Similarly, the more industries covered, the less the pressure of CO_2 reduction in each coverage industry.

Table 4
Enterprises burden of enterprises in ETS market in all countermeasure scenarios (unit: billion yuan).[a]

Enterprises	ELC	ECC	ENINT	ENPRO	EUETS-III
COL	0.00	0.00	0.00	138.94	115.02
O_G	0.00	0.00	0.00	26.69	21.92
PAP	0.00	0.00	30.65	0.00	25.10
CMT	0.00	116.31	104.90	0.00	87.21
CMC	0.00	63.25	28.48	0.00	23.34
STL	0.00	0.00	236.47	0.00	206.14
ELC	915.17	856.44	769.59	770.94	632.17
CST	0.00	0.00	13.34	0.00	10.93
TRA	0.00	0.00	14.90	0.00	12.19
Total	915.17	1036.00	1198.32	936.58	1134.01

[a] Agriculture, fertilizer, equipment, other industries and service are not covered in ETS market in all countermeasure scenarios, so we have omitted these sectors in this table.

5.3. The impact on CO_2 reduction

5.3.1. CO_2 abatement

Fig. 9 illustrates CO_2 reduction capacity of ETS market in all countermeasure scenarios from 2021 to 2030. The reduction capacity is calculated by comparing CO_2 emissions in countermeasure scenarios with that in BaU scenario. CO_2 emissions reduction effect will increase over time from 1.29 to 1.33 billion tons of CO_2 (Bt-CO_2) in 2021 to

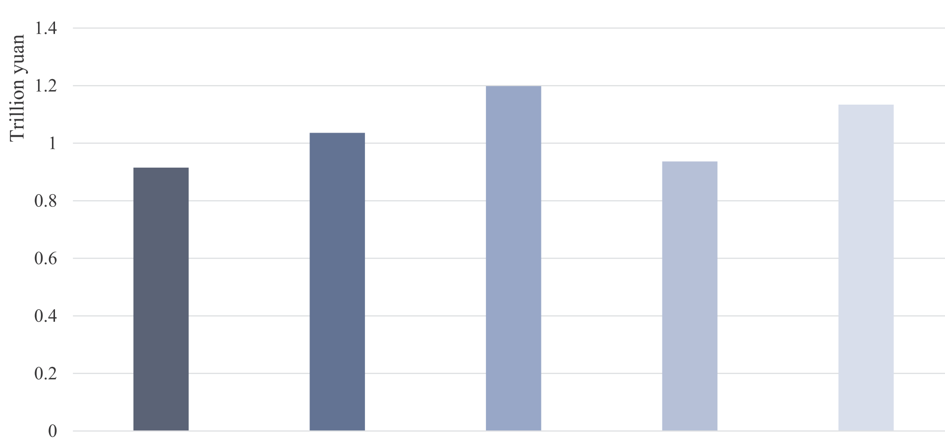

Fig. 8. Total enterprises burden in ETS market in all countermeasure scenarios.

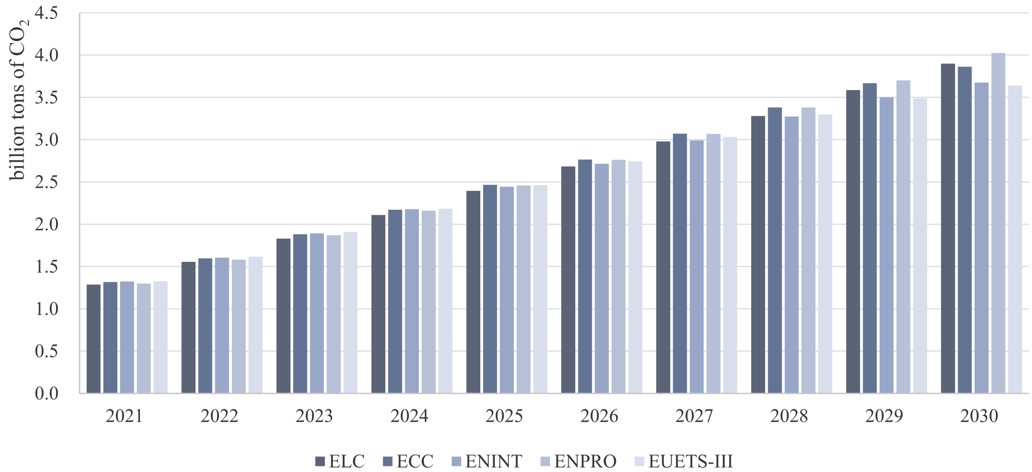

Fig. 9. CO_2 abatement in all countermeasure scenario from 2021 to 2030.

3.64–4.02 Bt-CO_2 in 2030. Different industrial coverage will cause different CO_2 abatement capacity, and the differences will increase as time goes by. For instance, CO_2 reduction will be 3.90, 3.86, 3.68, 4.02, and 3.64 in ELC, ECC, ENINT, ENPRO, and EUETS-III scenarios, respectively. We found that the CO_2 reduction effect will be highest when only energy production industries participate in ETS market, while the effect will be lowest when energy production industries and energy intensive industries are both covered into ETS market. The performance in ENINT scenario will be not as well as others except for EUETS-III scenario, which indicates that it may not be reasonable for China to cover energy intensive industries into ETS market and the only covered energy production industries may have better performance in CO_2 mitigation. The main reason may be that if only energy intensive industries are covered in ETS market, the energy consumption cost in these industries will increase, then the resource (carbon allowance) will be redistributed in these industries. However, if only energy production industries are covered in ETS market, the energy prices will increase, then the resources will be reallocated in all industries. So the CO_2 abatement performance in ENPRO scenario will be the best among these countermeasure scenarios.

5.3.2. *Carbon intensity*

Fig. 10 illustrates carbon emission intensity in all scenarios from 2017 to 2030. carbon intensity is calculated by CO_2 emissions divided by GDP, which is an indicator to measure energy efficiency or the level of low carbon development. ETS can reduce carbon intensity significantly: 0.167 tons of CO_2/thousand yuan in BaU scenario while 0.163 tons of CO_2/thousand yuan in countermeasure scenarios in 2017, and the number will be 0.145 and 0.101–0.105 tons of CO_2/thousand yuan in BaU scenario and countermeasure scenarios in 2030. The results are similar to the results of CO_2 reduction. The ENPRO is the scenario with the lowest carbon intensity in 2030, while ENINT and ENPRO will emerge as the highest in 2030. The results denote that covering energy production industries will have better CO_2 reduction efficiency. And we also noticed that if China's government follows the original plan of coverage pattern (ECC or ENINT scenario) or phase III of EU-ETS (EUETS-III scenario), the reduction efficiency will not be as good as the one achieved by maintaining the status quo (ELC scenario).

6. Conclusion and policy implications

6.1. *Conclusion*

This paper establishes five counter-measure scenarios with different coverage industries according to relevant document and experience and constructs a dynamic recursive computable general equilibrium model to answer the question on what China should do after electricity sector participates in the emission trading market. The following conclusions were obtained:

More coverage industries in ETS market will lead to a higher GDP performance and less ETS price. However, ETS only covers energy intensive industries, so the total enterprises‘ burden will be higher than that in scenarios with other coverage choice. And the more industries are covered, the less the pressure of CO_2 reduction in each coverage industry. The coverage of energy production sectors will directly affect the price increase in the energy production industry, and will indirectly drive the price of CO_2 reduction of other companies through price factors. We found that the CO_2 reduction effect will be highest when only energy production industries are covered into ETS market, while the effect will be lowest when energy production industries and energy intensive industries are covered into ETS market. The main reason may be that if only energy intensive industries are covered in the ETS market, the energy consumption cost in these industries will increase, then the resource will be redistributed in these industries. However, if only energy production industries are covered in ETS market, the energy consumption cost in energy production industries will increase and the energy prices will increase so that the resources will be redistributed in all industries. So the CO_2 abatement performance in ENPRO scenario will be the best among these countermeasure scenarios. And we also noticed that if China's government follows the plan of coverage pattern of National Development and Reform Commission or phase III of EU-ETS, the emissions reduction efficiency will not be as good as maintaining the status quo. Exports in all industries will decrease with a different range while ETS impact on imports is not as significant compared with that on export.

We summarize several key conclusions of this paper in Table 5. The impacts on GDP and CO_2 abatement are synchronous among different industrial coverage options. It shows that higher emission reductions are bound to higher economic costs. However, the result of carbon intensity shows that higher reduction efficiency is proofed in the EUETS-III scenario, which is one of this paper's implications. Carbon prices are negatively correlated with the number of industries covered. Total enterprises burden caused by ETS is not directly related to emission reduction.

We notice that ENPRO scenario shows a greater performance in emission reduction and carbon intensity. In theory, as more industries are covered by carbon trading, the cost of social emission reduction will be lower. The emission reduction may not necessarily increase with wider coverage, but the carbon intensity will certainly decline.[2] But why

[2] Generally speaking, emission reduction is controlled by total amount, but emission reduction efficiency is related to mechanism design.

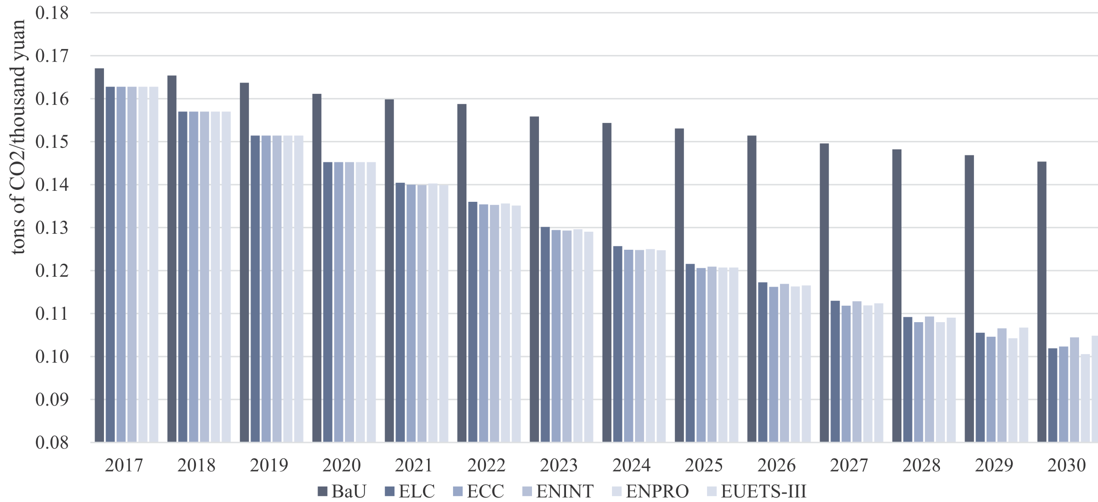

Fig. 10. Carbon emission intensity in all scenarios from 2017 to 2030.

Table 5
Key conclusion of this paper.

Indicators	Performance
GDP (from high to low)	EUETS-III > ENINT > ECC > ELC > ENPRO
Carbon Price (from high to low)	ELC > ECC > ENPRO > ENINT > EUETS-III
Total enterprises burden (from high to low)	ENINT > EUETS-III > ECC > ENPRO > ELC
CO_2 abatement (from high to low)	ENPRO > ELC > ECC > ENINT > EUETS-III
Carbon intensity (from low to high)	ENPRO > ELC > ECC > ENINT > EUETS-III

does the result show that carbon intensity in ENPRO scenario is lower than that in EUETS-III scenario? The author speculates that in addition to the role of the carbon trading market itself, the commodity market plays a key role in reducing emissions. As in Fig. 5 shows, energy prices increase significantly in ENPRO scenario, especially the dominant energy, coal. That will encourage energy intensive enterprises to reduce energy use. From this point of view, carbon trading seems to be a policy like carbon tax policy. Is the policy more effective, and why? This worth considering in our next study.

6.2. Policy implications

According to our conclusion and the situation in China's economy, energy and environmental policy, and ETS market, this paper first suggests the design sector coverage should be changed, if the design remains unchanged, this paper will suggest levying carbon tax as a supplement of ETS market:

1) The choice of coverage industries: this paper suggests that China government should not follow the patterns of the National Development and Reform Commission to cover energy intensive industries into ETS market. It's better to replace them with the energy production industries. The performance of CO_2 emissions reduction capacity and CO_2 emissions reduction efficiency in ETS market with energy intensive industries covered will not be as well as those with energy production industries covered, which indicates that it may not be reasonable for China to cover energy intensive industries into ETS market, therefore, covering only energy production industries may have better performance in CO_2 mitigation and economy protection.
2) Carbon tax as a supplement: carbon tax for energy production sectors can also help to balance the energy, environment, and economy in China if the coverage industries in China's national ETS market are energy-intensive industries. Higher carbon tax and lower ETS prices may also be helpful to reduce CO_2 emissions and protect the economy.

6.3. Limitations

In China, the first batch of coverage only includes the power generation industry. It is very difficult to separate the power generation industries and transmission industries in an input-output table, as we need to know the situation of the intermediate input. So like most previous studies this paper uses the account of electricity industry to represent power generation industry.

Declaration of competing interest

We declare that there is no conflict of interest.

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